

1. Parametrization of the instrumental spectral response function (ISRF)

Steffen Beirle, Johannes Lampel, Christophe Lerot*, Holger Sihler, Thomas Wagner

MPIC Mainz, *BIRA Brussels



AURA science team meeting 2016, Rotterdam

1. Parametrization of the instrumental spectral response function (ISRF)

2. Parametrization of changes of the instrumental spectral response function (ISRF)

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Motivation

- Instrumental Spectral Response Function (ISRF)
("Slit Function") is a key quantity in spectroscopy:
 - Wavelength calibration
 - DOAS: cross-sections at instrument resolution
 - ISRF can be measured (spectral light source, tunable laser)
 - But:
 - ISRF depends on wavelength
 - ISRF may change over time
- Parametrization required

Motivation

If “true” ISRF not known:

- Can be determined by fitting a high-resolution solar spectrum
- Standard procedure in DOASIS, Q-DOAS...
- Gaussian (1 free parameter): often working, but not always best choice...

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If ISRF is measured accurately:

- Dedicated parameterizations for specific instruments
- OMI: “Broadened Gaussian”, sum of Gaussian and flat-topped Gaussian-like function with exponent 4
- Good representation of measured ISRF
- Many parameters

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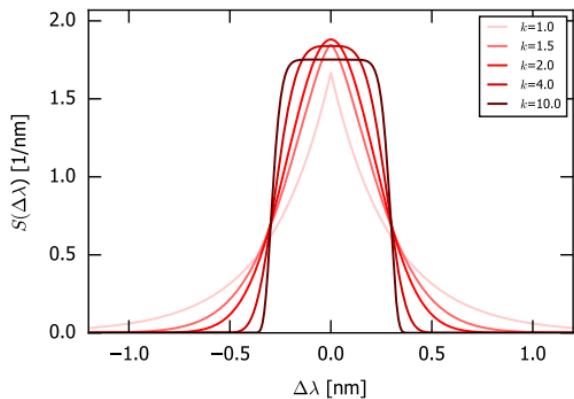
Here: proposal for a new parametrization which covers a wide range of possible shapes by few parameters

The “Super Gaussian”

$$e^{-(\frac{x}{w})^2} \rightarrow e^{-|\frac{x}{w}|^k}$$

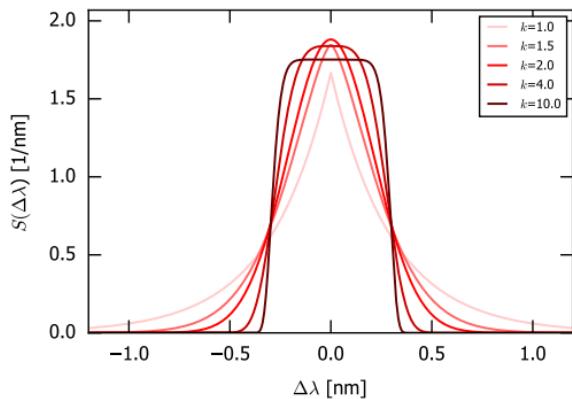
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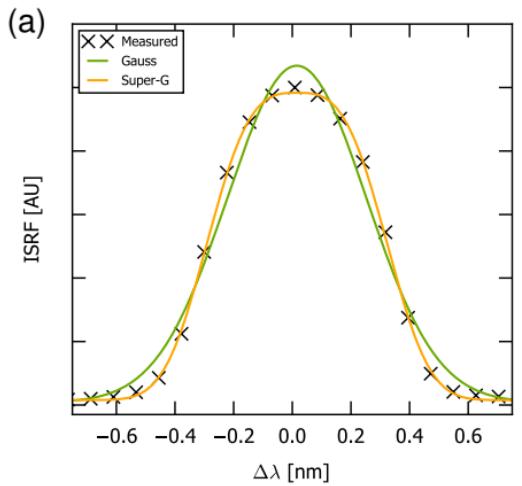
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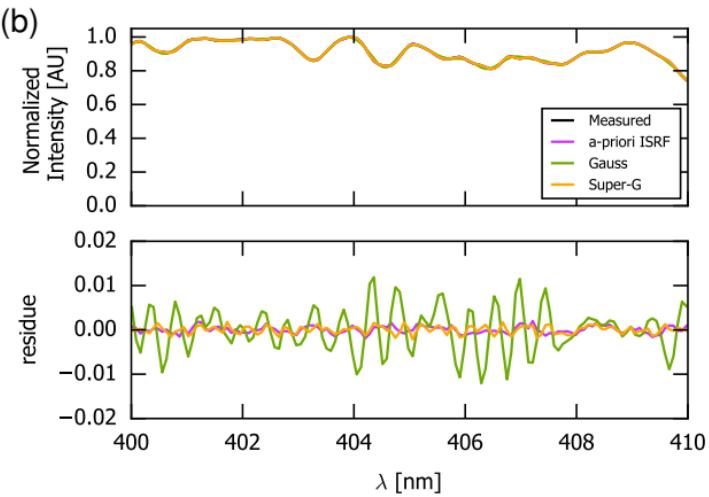
- Used in laser physics to describe beam cross-section
- w determines width; $\text{FWHM}=2(\ln 2)^{1/k} \times w$
- k determines *shape*
- Wide range of shapes can be represented by 2 parameters only! (3-4 for asymmetric extension)

AVANTES spectrometer

Hg line (404.66 nm)



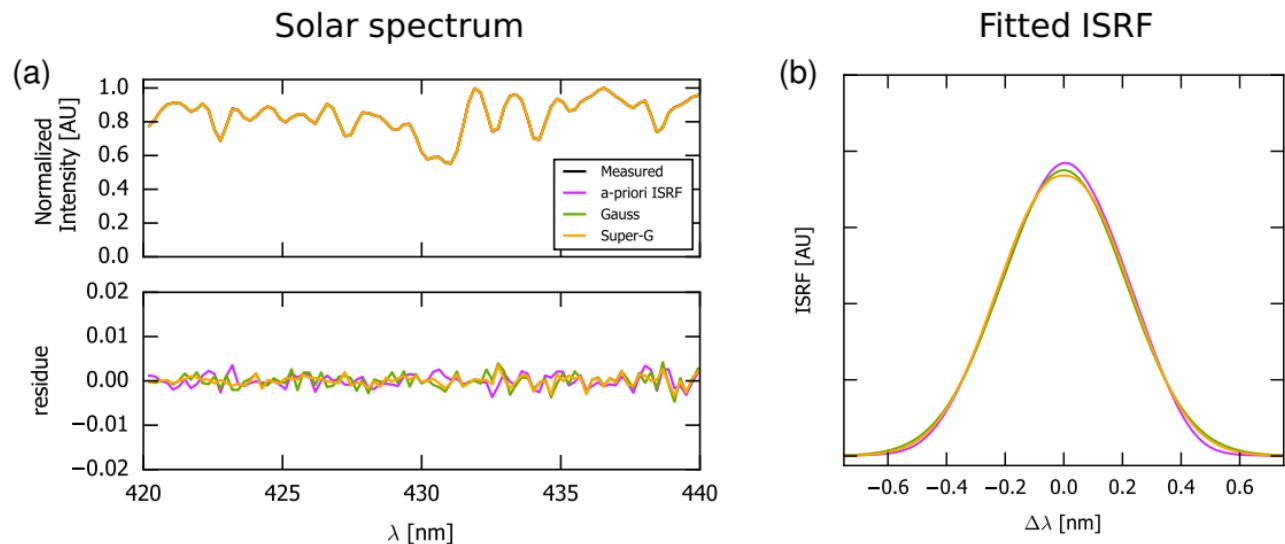
Solar spectrum



ISRF model	FWHM [nm]	w [nm]	k	RMS [%]
Gauss	0.560	0.336	$\equiv 2$	31.10
Super G.	0.620	0.348	3.15	6.77

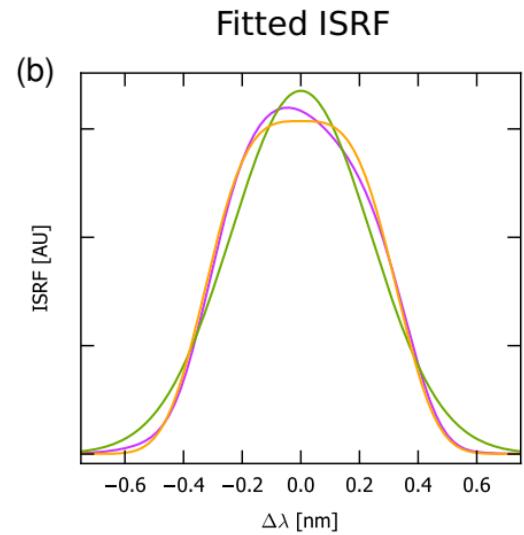
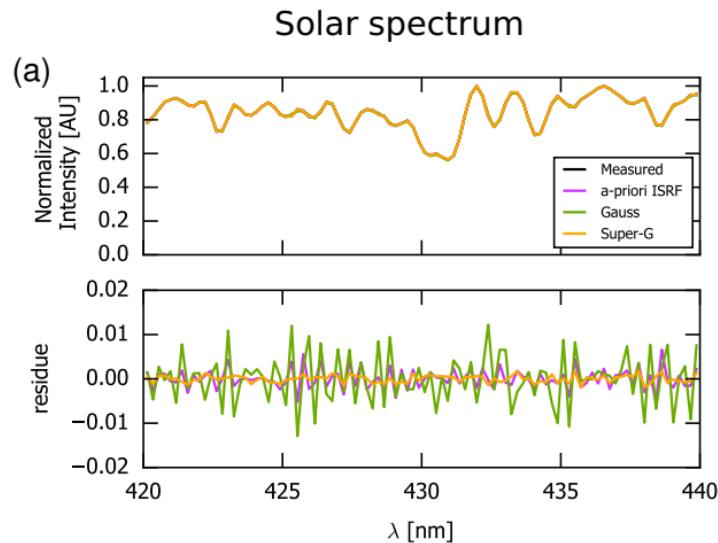
ISRF model	w [nm]	k	RMS [%]
a-priori			0.81
Gauss	0.353	$\equiv 2$	5.00
Super G.	0.339	3.28	0.88

GOME-2



ISRF model	w [nm]	k	RMS [%]
a-priori			1.51
Gauss	0.301	≡ 2	1.46
Super G.	0.306	2.17	1.02

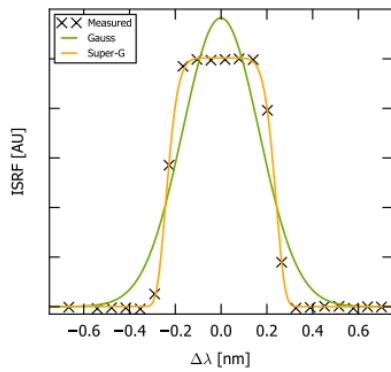
OMI



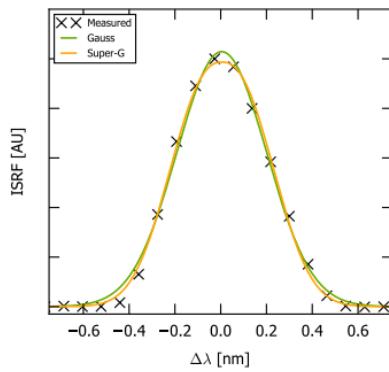
ISRF model	W [nm]	k	RMS [%]
a-priori			2.29
Gauss	0.336	≡ 2	5.64
Super G.	0.362	3.44	0.85

TROPOMI

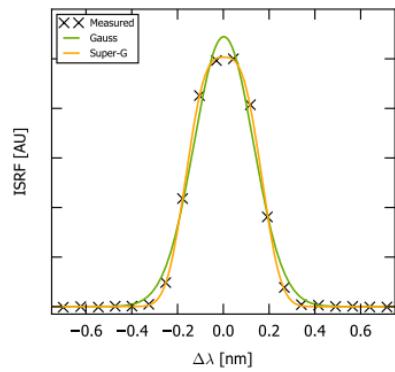
UV
 $\approx 300 \text{ nm}$



UVIS
 $\approx 400 \text{ nm}$



NIR
 $\approx 725 \text{ nm}$



*TROPOMI sample ISRF measurements provided by Antje Ludewig/Joost Smeets
(KNMI)*

Conclusions I:

- Super-Gaussian is a powerful parametrization of the ISRF for many instruments
- Wide range of ISRF shapes can be parameterized by only 2 parameters! (3-4 if asymmetric)
- SG ISRF can be derived from measured spectra based on Fraunhofer lines

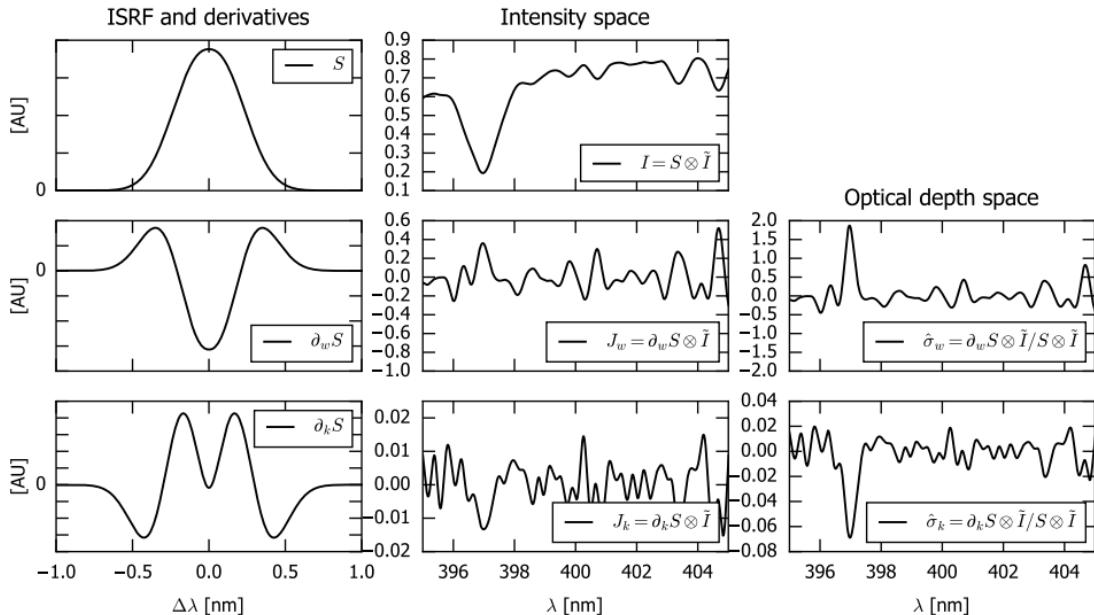
Part II: Parameterizing *changes* of the ISRF

ISRF might change over wavelength and time

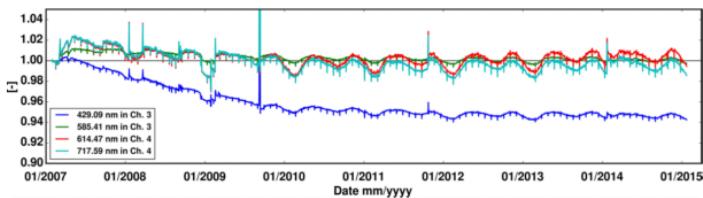
→ Parameterize the resulting spectral structures by a Taylor expansion

- Linearisation: Makes the fit more stable (no local minima) and $> 100 \times$ faster
(compare Beirle et al., AMT, 2013)
- SG is particularly suited: 2 parameters with distinct meaning (width and shape)

- Let P be a parametrization of ISRF with parameter p
 - $\Delta P \approx \Delta p \times \partial_p P$.
 - $\Delta I = \Delta p \times J_p$, with $J_p = \partial_p P \otimes \tilde{I}$
 - $\Delta \tau = \Delta p \times \hat{\sigma}_p$, with $\hat{\sigma}_p = \frac{\partial_p P \otimes \tilde{I}}{P \otimes \tilde{I}}$
- λ dependency:
 $*(\lambda - \lambda_0)$.

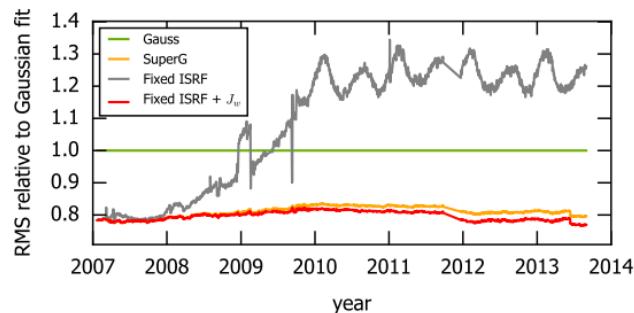
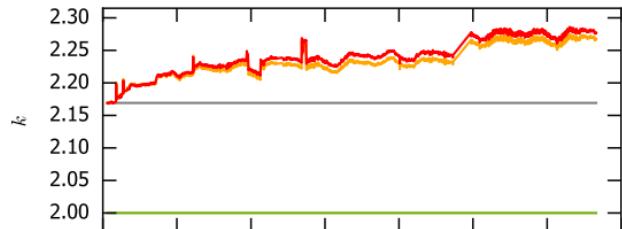
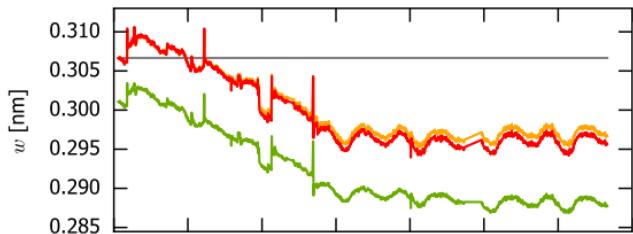
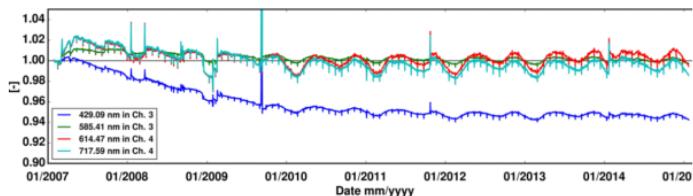


Application I: GOME-2 ISRF long-term changes



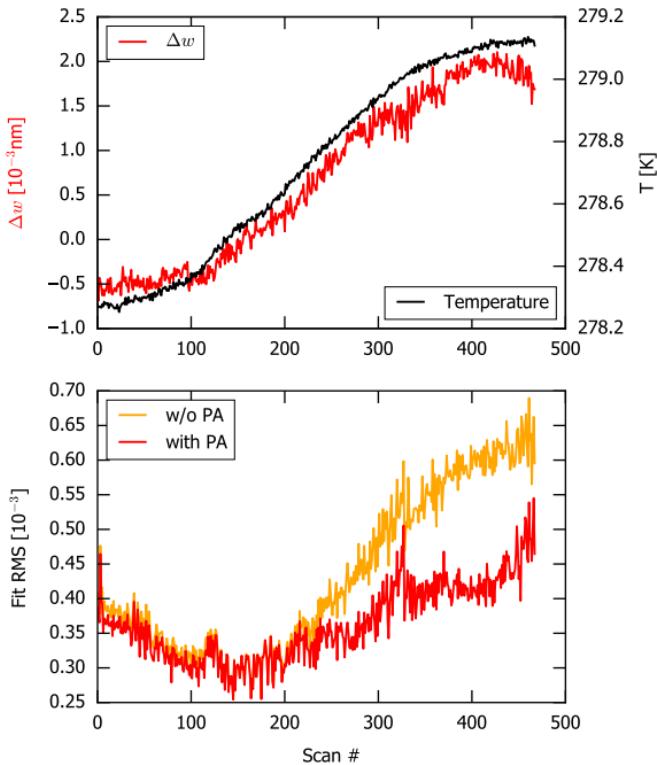
Munro et al., AMT, 2016

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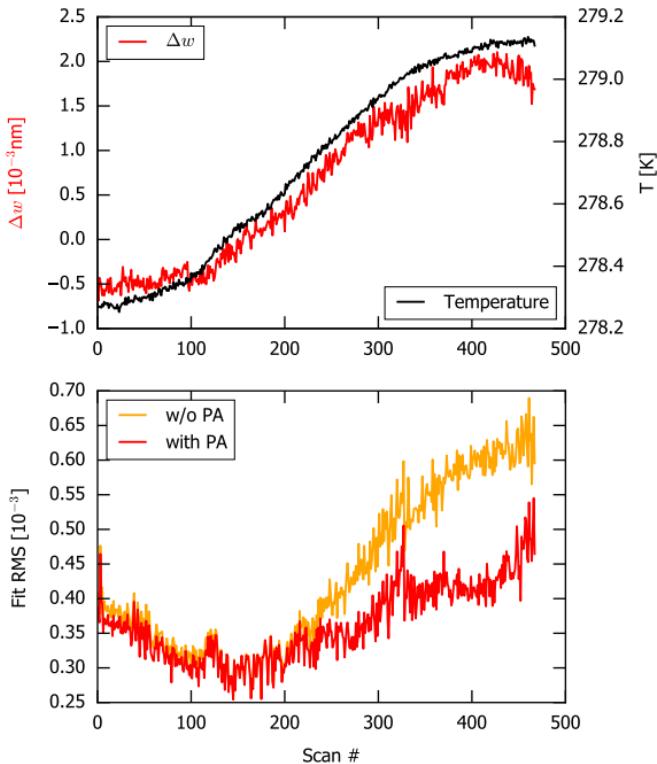


Munro et al., AMT, 2016

Application II: GOME-2 ISRF in-orbit changes

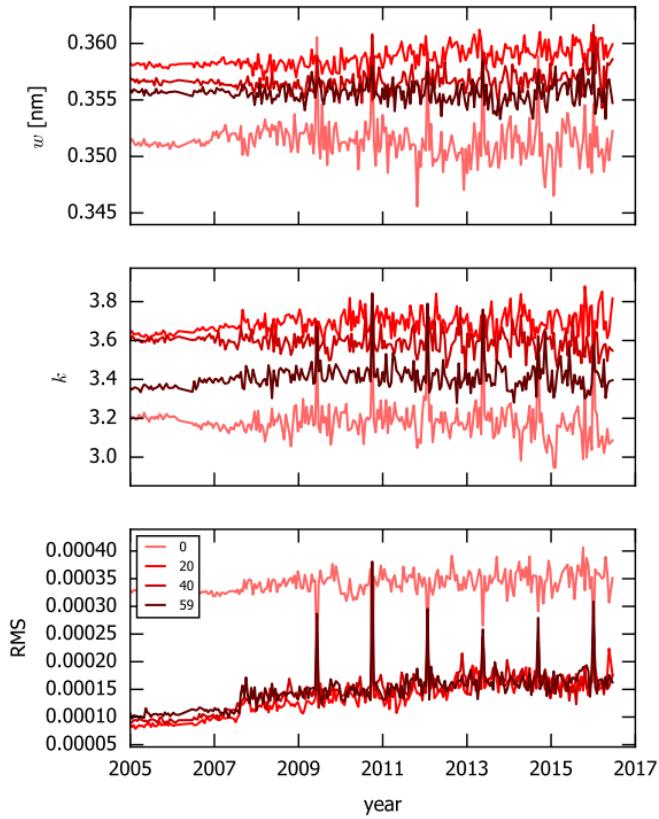


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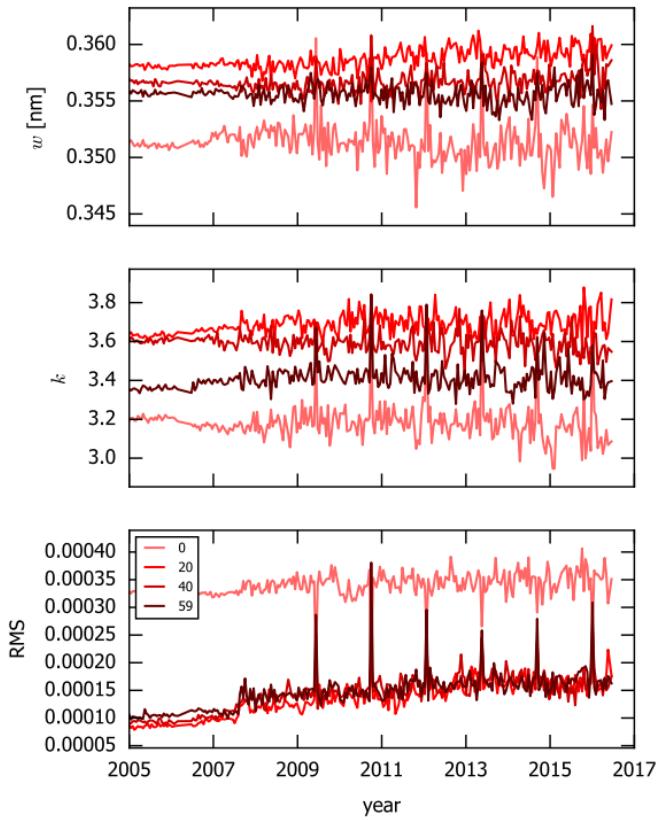


GOME-2 ISRF gets broader along orbit
by almost 1% due to warming
→ significant impact on DOAS fit

Application to OMI



Application to OMI



- long-term: no indication
for change of ISRF

- in-orbit: dito

Conclusions II

- Changing ISRF results in spectral structures
affecting DOAS analysis

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- This can be accounted for by “Pseudo-absorbers” derived from Taylor expansion
- For a SG param, changes of the width and the shape of the ISRF can be determined separately
- OMI is a very stable instrument